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BLAST-HOLE DIAMOND DRILLING IN CALIFORNIA MINES

BY

D. W. BUTNER

I C. 7451,
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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By D. W. Butner[2]

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SUMMARY

The blast-hole method for drilling and breaking ground is not new to the mining industry. For several years it has been used rather extensively in Canada, particularly in the gold mines, where it was first developed and where the major advances in the technique as applied to present-day mining problems have been made. At present, 40 mines in Canada and the United States are using the method in one form or another, and from all indications its use will increase in the future.

In two California mines, blast-hole diamond drilling is now used for a part of or for all stoping operations, and in one of these it is used to some extent in development work. At the Mountain Copper Co.'s Hornet mine in Shasta County, about 50 percent of the pyritic sulfide ore produced is mined by the blast-hole method, and the U. S. Vanadium Corp. mines 80 percent of the ore produced at its Pine Creek tungsten mine in Inyo County by this method. At Pine Creek, long-hole drilling and blasting is used for mining pillars also, and in pre-stoping development.

The blast-hole diamond-drilling method is not applicable to all types of ore bodies. A third property in California, the El Dorado Limestone Company, El Dorado County, tried the method for several months in 1943 and 1944, but, owing to certain factors that greatly increased mining cost, the company soon returned to conventional mining methods.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7451."

[2] Mining engineer, Reno (Nev.) Division, Mining Branch, Bureau of Mines.

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After using blast-hole methods for several years, the management at both the Hornet and Pine Creek mines have decided that the advantages the method has over conventional mining methods more than offset the additional expense involved in the necessary experimental work. The advantages such as safer working conditions for the miner, increased tonnage per man shift, and a steadier production rate are major factors in the decision to continue use of blast-hole diamond drilling at these properties.

INTRODUCTION

According to Olof V. Lindqvist, research engineer, the first core drill using black-carbon or diamond bits was devised by Rudolph Lischot in 1863. This drill was to be used as a means of reducing the high cost of blast-hole drilling at the Mount Cenis railroad tunnel in the French-Italian Alps. Apparently the drill accomplished its purpose, as in the following decade core drills were used extensively for both blast-hole and exploratory drilling. As a natural result, the demand for black carbon increased, and the price rose until, in 1900, the cost of blast-hole drilling with diamond bits became prohibitive and the use of the bits was virtually limited to exploratory work.

The rise in price of black carbon from $2 per carat in 1870 to $150 per carat in 1929 was a major factor in the development of a new type bit, which was set with small imperfect crystalline diamonds or bort. Bort was a by-product of the diamond industry, and these small stones were plentiful and inexpensive. Setting of these small stones was at first done by hand; later, however, a mechanical method for setting was devised and the cost of the bits was reduced further. At present, bit manufacturers use various methods for forming cast or processed bits, the matrix or metal alloy usually being poured into a mold containing the borts. In a process recently developed, powdered metal alloys are used to make up the matrix. Manufacturers using this method claim that better control of the composition of the bit is obtained, which permits construction of bits to more exacting specifications.

With the development of a better technique in bit manufacturing, combined with a comparatively lower cost of bort, the cost of blast-hole diamond drilling has decreased sufficiently to again permit its use in mining. At present, good-quality bort is becoming scarce in the United States and the price is rising. If this is a result of wartime conditions, the situation will probably right itself.

Past experience has indicated that blast-hole diamond drilling can best be employed in mining wide or thick deposits with strong and fairly regular walls. Obviously, the method cannot be used on ore bodies with weak walls, which require timber or pillar support.

ACKNOWLEDGMENTS

This publication was prepared under the direction of Lowell B. Moon, chief of the mining branch. The work of preparing this paper was under the general supervision of A. C. Johnson, chief of the Reno Division, Mining Branch, and Spangler Ricker, supervising engineer in California.

Special acknowledgment is tendered the following officials for their assistance and cooperation in the preparation of this report: Laurence T. Kett, assistant general manger of the Mountain Copper Co.; J. C. Huseby, general superintendent, C. W. McClung, mine superintendent, and Paige Bagley, chief engineer; A. F. Boyd, general superintendent of the U. S. Vanadium Corp., W. R. Jones, mine superintendent, and Churchill Scott, chief engineer; J. H. Bell, manager of the El Dorado Limestone Co.; and Gilbert Longtin, president of the Longtin Drilling Co.

A series of articles on blast-hole diamond drilling was published in the Engineering and Mining Journal of October 1945, January 1946, and March 1946. In a booklet entitled Blast Hole Diamond Drilling, by Olof V. Lindqvist (published by J. K. Smit & Sons, Inc., New York, 1944), the subject is briefly described and discussed. A number of articles describing the various applications of diamond drilling to mining methods have appeared in the Proceedings of the Canadian Institute of Mining and Metallurgy.

MOUNTAIN COPPER CO.

At the Hornet mine of the Mountain Copper Co., which is situated at Iron Mountain near Matheson, Shasta County, Calif., a pyritic deposit of sulfide ore has been mined almost continuously for the past 50 years. Mineralization by replacement of instrusive alaskite porphyry has produced large bodies of pyrite. Contained in these pyritic ore bodies are areas with sufficient chalcopyrite and sphalerite to constitute low-grade copper-zinc ore.

At present the company is producing two classes of ore - a massive pyrite and a mill-grade ore containing pyrite and varying amounts of copper and zinc sulfides. The massive pyrite ore is crushed at the property and shipped without further treatment to manufacturers of sulfuric acid. From the low-grade copper-zinc ore, which is treated in the company's mill, two products - a copper and a zinc concentrate - are produced.

During the last 3 years the company has been using blast-hole diamond drilling methods for mining approximately 50 percent of the ores produced from the Mattie and Richmond ore bodies in the Hornet mine. The method, first employed on the Mattie ore body, is now being used with modifications in a series of stopes on the Richmond ore body.

Use of long diamond-drill blast holes at the Hornet mine has reduced the cost of breaking ore and increased the tonnage of profitable ore in the deposit. Accident rates, particularly for injuries from falling rocks, have decreased notably since the method was introduced.

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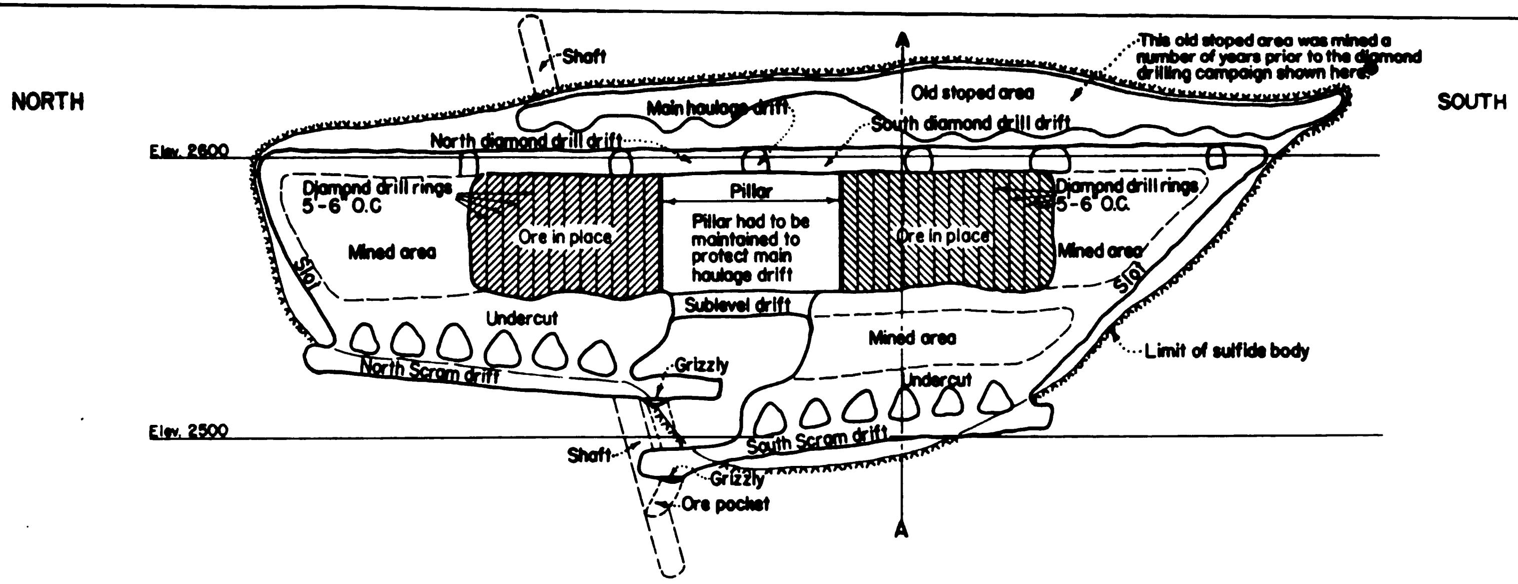
Mattie Ore Body

The Mattie ore body had been discovered, partly developed, and a minor amount of stoping accomplished when the management decided to diamond-drill blast holes. As may be seen from figure 1, the ore body was a boat-shaped mass lying approximately horizontal and surrounded by alaskite porphyry. The ore was a complete replacement of porphyry by sulfide minerals, principally pyrite but having segregated areas containing commercial amounts of chalcopyrite and spahlerite commonly the marmatite variety.

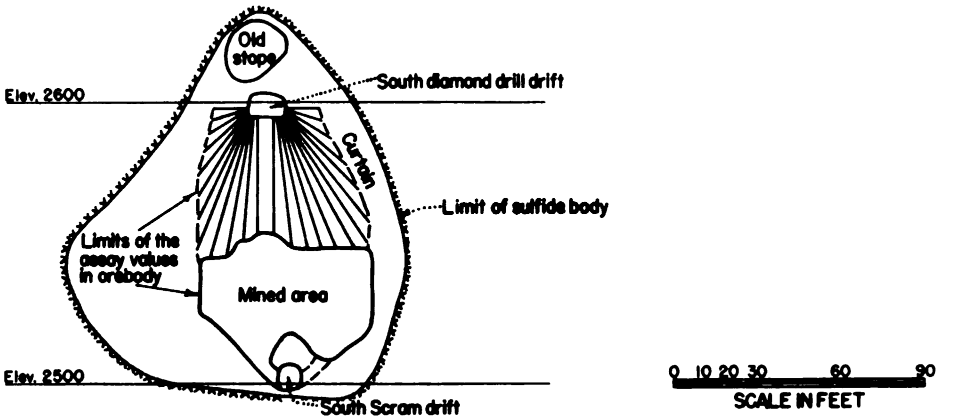
Preliminary development included a drift along the ore body at the level of the main haulage and another at the bottom of the ore. Above this lower drift the ore was undercut from wall to wall, and an intermediate drift was driven between the undercut and the main level. Near each end of the deposit a slot was broken across the ore and carried upward by shrinkage to the upper limit of the ore block; then the broken ore was drawn, and the slot was left empty. A diamond drill was set up in the intermediate level near the slot, and successive vertical rings of holes were drilled. The engineers made sections of the ore body at 5-foot intervals. On each section the holes were laid out with the inclination and depth of each hole indicated, as well as the limit to which each hole was to be charged with explosive. When starting a ring of holes on a given section, the driller was givena print of the diagram of that section, and drilling and loading were done according to the lay-out shown. The drilling patterns were designed to give the holes a 5-foot burden, and the distance between bottoms of holes was approximately 5 feet. All the holes in one ring were fired simultaneously by means of primacord with No. 6 caps. The ore broken by the blast was passed through draw holes to the lower drift, moved by scraper to ore pockets at a shaft, and hoisted to the main level. Electrical trains delivered the ore to the mill bins.

The amount of secondary blasting required varied with the degree of natural fracturing in the ore. It was found that the ore stood in the walls and backs of open stopes better than the enclosing porphyry. Consequently, a "curtain" of ore was left on the stope walls and backs when approaching limits of the ore body. The shape of the stoped area was not regular, but was determined by assay. Thus the mined portion of the deposit represents the volume that had a large enough content of combined copper and zinc to be profitable.

All diamond drilling in this ore body was done under a contract for the drilling, loading, and firing of the holes. Compressed air, water, and explosives were supplied by the company, and the contractor was paid 50 cents per ton of ore broken. The contractor used air-driven CP-5 drills with EX rods and 1-7/16 inch concave noncoring bits not channeled on the face for water circulation. The contractor installed a small plant at Redding, in which bits were made for his work at various places. He has developed a powder alloy that gives highly satisfactory service and has applied for a patent thereon.


NORTH
SOUTH
Shaft
This old stoped area was mined a number of years prior to the diamond drilling campaign shown here.
Old stoped area
Main haulage drift
South diamond drill drift
North diamond drill drift
Elev. 2600
Diamond drill rings 5-6' O.C.
Pillar
Pillar had to be maintained to protect main haulage drift
Ore in place
Ore in place
Diamond drill rings 5-6' O.C.
Mined area
Mined area
Slot
Slot
Sublevel drift
Undercut
Mined area
Limit of sulfide body
Grizzly
North Scram drift
Undercut
Elev. 2500
Shaft
South Scram drift
Grizzly
Ore pocket
A
A

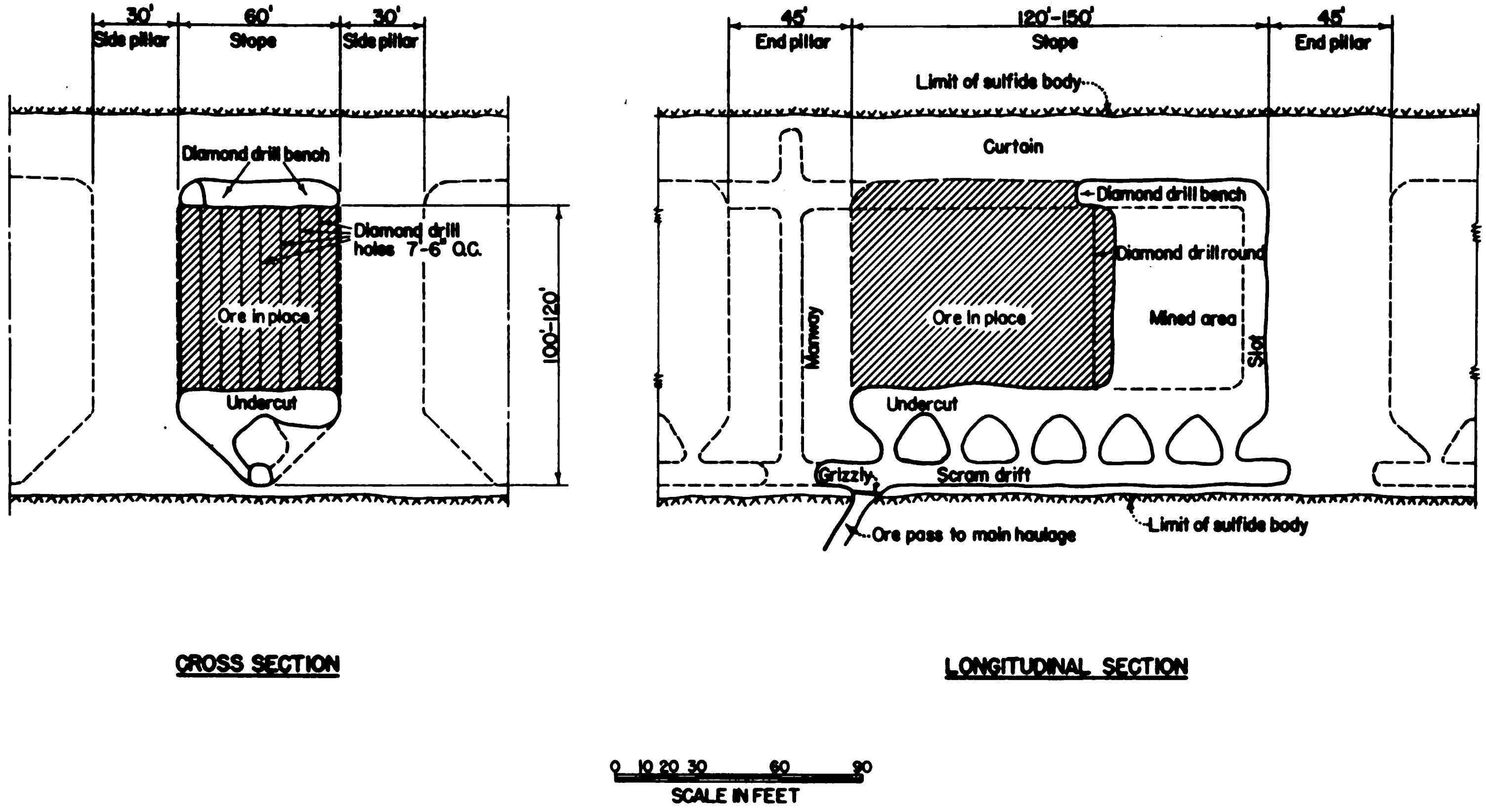
LONGITUDINAL SECTION



CROSS SECTION THROUGH A-A
Looking North

Courtesy of The Mountain Copper Co., Ltd.

FIGURE I. DIAMOND DRILLING IN THE MATTIE OREBODY, SHASTA COUNTY, CALIFORNIA.



CROSS SECTION

LONGITUDINAL SECTION

Courtesy of The Mountain Copper Co., Ltd.

FIGURE 2. DIAMOND DRILLING IN THE RICHMOND OREBODY, SHASTA COUNTY, CALIFORNIA.

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Richmond Ore Body

The part of the Richmond ore body developed for mining by diamond-drill holes is massive pyrite without commercial amounts of copper or zinc. This material is crushed and sold without metallurgical treatment. Development for a room-and-pillar arrangement of stopes was begun by driving drifts below the projected stopes, as shown in figure 2. These drifts, serving as scraper ways for moving the ore, have been called scram drifts. The large openings, without chutes, through which ores move by gravity from stope to drift are designated as draw holes. Draw holes were raised from the scram drifts, and the entire block was undercut, leaving saddle pillars between holes. A slot was cut upward across the full width and to the height of the stope block at the end farthest from the main drift. So far, preparation of the ground was the same as in the Mattie ore body. In the Richmond deposit a sublevel was drifted along one side of the top of the block to be stoped. From this sublevel a bench about 10 feet wide was blasted off across the top of the slot. On this bench the diamond drills were set up, and a row of vertical and parallel holes was drilled downward through the block to the undercut.

The stope blocks shown in figure 2 are 120 to 150 feet long, 60 feet wide, and 100 to 130 feet high. Pillars 30 feet wide on the sides and 45 feet wide at the ends are left around stopes. As in the Mattie ore body, the ore is not broken to the porphyry walls or to the back, but a curtain of several feet of ore is left. The reason for this is that the alaskite spalls from the walls and back as soon as exposed to the air, whereas the ore stands well in the open stopes. Texture and hardness of the ore vary considerably, causing differences in speed of drilling, degrees of fragmentation, and amount of overbreakage. Blasting is done with 60 percent gelatin dynamite. The holes, drilled in a row, are given a burden of 7 feet and are drilled parallel 7 feet apart. Only one row of holes is drilled from the bench before blasting. Then another bench cut is slashed across the top of the face for the next row. As each hole is completed, the drill helper loads it with 60 percent gelatin dynamite; and when the drill is removed from the last hole, there is only one load to place before the round is ready for firing. There is always some overbreak in blasting. This is not often troublesome in itself but produces large pieces of broken ore, thus increasing the amount of secondary blasting in the drift. Scrapers pull the broken ore along the drift to a grizzly having 12-inch spacing. Oversize not sufficiently broken at the draw holes is reduced at the grizzly, through which the material drops into an ore pass leading to the main haulage level.

Vertical drilling from a bench is advantageous to the contractor and to the company. The holes are easier to drill and load than inclined holes, and they do not require the detailed planning of lay-out on each ring. This relieves the engineering department of considerable work. Another advantage over rings drilled fanwise is the elimination of occasional bootlegging or incomplete breaking of side holes. Also, the entire footage drilled is loaded and blasted. In bench drilling, side holes extend the entire depth of the face. One disadvantage of bench drilling is the necessity of a

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separate set-up for each hole, and another drawback is that drilling cannot be carried far ahead of blasting. Advance drilling is limited to one or two rows of holes.

When diamond drilling of the Richmond ore began, the basis of payments to the contractor was changed. The footage drilled, instead of the tonnage broken, is paid for under the new arrangement. This is a simpler and more satisfactory basis of settlement. The general rate is $1.50 per foot, though $1.75 per foot is paid for drilling in difficult ground. Volume-to-weight ratio for the ore is 7 cubic feet to a ton. Ore broken per foot of hole ranges from 6.6 to 10 tons, and efficiency of explosives ranges from 0.08 to 0.1 pound of powder per ton of ore. The cost of the work done under contract (that is, drilling, loading, and firing of stoping blast holes) averages 17 cents per ton of ore. Some stopes are drilled with horizontal and inclined fanned holes as special conditions are met, but bench drilling remains standard stope practice when long holes are used.

During the last 3 years, 50 percent of the ore produced from the Hornet mine has been broken with diamond drill-hole blasting. Reduction in breaking costs through use of diamond drilling probably has increased the tonnage of workable ore reserves at the property.

Standard-type rock drills are used in development work, stope preparation, and in mining most of the milling ore containing copper and zinc sulfides.

Mountain Copper Co. officials agree that blast-hole diamond drilling has advantages well worth retaining in future operations.

EL DORADO LIMESTONE

This mine in El Dorado County produces crushed limestone for the sugar and steel mills and for glass manufacturers and processors of building materials on the Pacific Coast. During the war, operations were seriously hampered by the labor shortage. To overcome this, diamond-drill holes were tried for blasting in stopes, but the method was abandoned within a few months. There were several reasons for this course. One was the cost, which nearly doubled the current direct expense per ton. Another was the inadequacy of installed air-compressor capacity for the simultaneous operation of hammer drills and diamond drills. A third reason for stopping the trial was poor fragmentation of the blasted rock, due to the blocky nature of the limestone and, more important to the method of stoping.

All of the drawbacks to use of diamond drills for production could have been lessened by more complete preparation. The limestone mined here is in an upturned stratum about 60 feet thick. A section of this bed several hundred feet in length horizontally is excellent limestone. The section of good-grade stone rakes southward in the bed like a shoot of ore in a vein. Silica and magnesium percentages increase north and south of the mine workings. The deepest level is now at 650 feet. Seasonal fluctuation causes the flow of water in the mine to vary between 150 and 200 gallons per minute. Most of the body of good stone is crystallized and is seamed with cracks and small fissures. Several small dikes of greenstone were found crossing the limestone, which is cut, also, by a narrow dike of fine grained basic rock. Except in sinking the shaft, these dikes did not interfere with operations.

At the time of the decision to try diamond drills for stoping, a block of ground was prepared for removal by the usual method. A haulage drift had been driven under the block, ore passes were raised, chutes were constructed, and the area was undercut. Additional preparation included three raises along the center line of the block, a sublevel drift connecting the raises 50 feet above the undercut, and a slot across the end of the block. Holes were then drilled in horizontal rings from the raises. They were given a 5-foot burden, and the ends of the holes were kept a minimum of 8 feet apart. When blasted, an incompletely shattered slab of rock dropped on the muck in the stope. The plan was to draw the broken ore through the chutes as in usual shrinkage-stope practice. This method produced large pieces of rock, some of which were buried under finer material and escaped secondary blasting in the stope. Large rocks soon blocked the chutes. Getting oversize material through a raise and chute is a slow and costly process. Aside from the seamed and blocky character of the limestone, the short drop and relative lack of disarrangement of fragments in the blasted slice as it fell on the broken ore tended to preserve the large pieces from breakage. Strength of explosive was varied from 35 to 75 percent in the search for the maximum shattering charge. The conclusion reached as a result of these trials was that there was little difference in the degree of fragmentation with any of the dynamites.

Drilling was done under contract. Payment was to be 75 cents per foot of hole when drilled. When the ground was blasted, payment was increased to bring the total to 50 cents per ton. Prices included loading and firing holes. Compressed air and explosives were furnished by the company. Subsequent agreements modified the basis of payment. Two CP-5 drills were used with EX rods and noncoring bits 1-7/16 inches in diameter. An average of 136 feet per machine shift was drilled in the period from November 1943 to May 1944, making a total of 46,470 feet of drilling. Blasting this footage of holes broke 54,000 tons of rock, or 1.16 tons per foot. Unit cost of the drilling was 53.9 cents per ton, and the additional cost of the supplementary development raised the direct cost of diamond-drilling to 64.4 cents per ton. This did not compare favorably with the cost of shrinkage stoping with hammer drills. At about the same time, 1943-44, a block of 37,000 tons was stoped with air drills, at a cost of 36 cents per ton. All direct mining charges were included in this figure.

J. H. Bell, manager of El Dorado mine, thinks it possible that diamond-drilling blast holes might be a better method than the conventional drilling now in use at his property. In his opinion, mistakes were made in the trial operation of the diamond-drill system and that the following changes would overcome the greatest obstacles to its adoption.

1. Use drift under the block as a scram drift, with large draw holes to pass the rock. This would obviate the chutes and allow access for secondary blasting.

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2. Use scrapers for slushing ore to grizzlies.

3. Follow the bench or similar method of drilling holes, so that each foot drilled would be used for breaking ore.

4. Carry the stopes nearly empty to increase the height of fall of the blasted ore.

5. Increase the compressor capacity at the mine sufficiently to care for the greater volume of air needed.

If these measures had been taken before the trial, diamond-drill blast holes might have succeeded in improving the operation. The company now uses its own diamond drill in underground development.

PINE CREEK MINE

The U. S. Vanadium Co. is mining a tungsten deposit on Pine Creek in Mono County, Calif. Bateman, of the Federal Geological Survey, rates it the largest known reserve of tungsten ore in the country.[3] The ore is tactite formed along a contact between granite and limestone, striking slightly west of north, and standing vertical. Locally, the walls vary to steep east or west dips. The usual contact metamorphic silicates are present in the tactite zone with disseminated scheelite. Powellite is present but not abundant. Unevenly distributed molybdenite and chalcopyrite increase the value of the ore. The molybdenite is found near the granite contact in tactite and sometimes in the granite wall of the zone, but the chalcopyrite is not so restricted in association. Some of the shallow ore carries copper carbonates. Although by no means uniform in width, the zone of metamorphism extends from the outcrop to the lowest depth at which it has been cut, a vertical distance of more than 2,000 feet. The north and south ore bodies are separated by a bulge in the granite wall. There does not appear to be much change in the type or grade of ore in depth, and there is no present indication of ore limit in depth. Occasional lenses of loose sand are encountered in the tactite body, which cause considerable trouble in drilling and loading.

The use of diamond drilling for stope blasting was begun at Pine Creek in 1942 and is still current. The system has some special advantages for mines whose operations are seasonal. The mine workings are at altitudes of 10,000 to 12,000 feet, where the winters are severe. A large reserve of drilled ore has been accumulated, and when ore is needed a ring of holes is loaded and blasted. The broken ore moves by gravity to the scram drift through draw holes. Large pieces are blasted by plugging or with 60 percent dynamite "plasters" and primacord. Each scram drift has a double-drum, 50-horsepower, electric scraper hoist slushing the ore in the drift to the grizzly. Ingersoll Rand and Sullivan machines equipped with 440-volt A.C. motors are used. Material passing the 22-inch spaced grizzly bars drops into a pocket, from which specially reinforced granby-type cars are loaded. Empty cars are

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[3] Bateman, Paul C., Pine Creek and Adamson Tungsten Mines, Inyo County, California: California Jour. of Mines and Geology, Oct. 25, 1945, p.233.

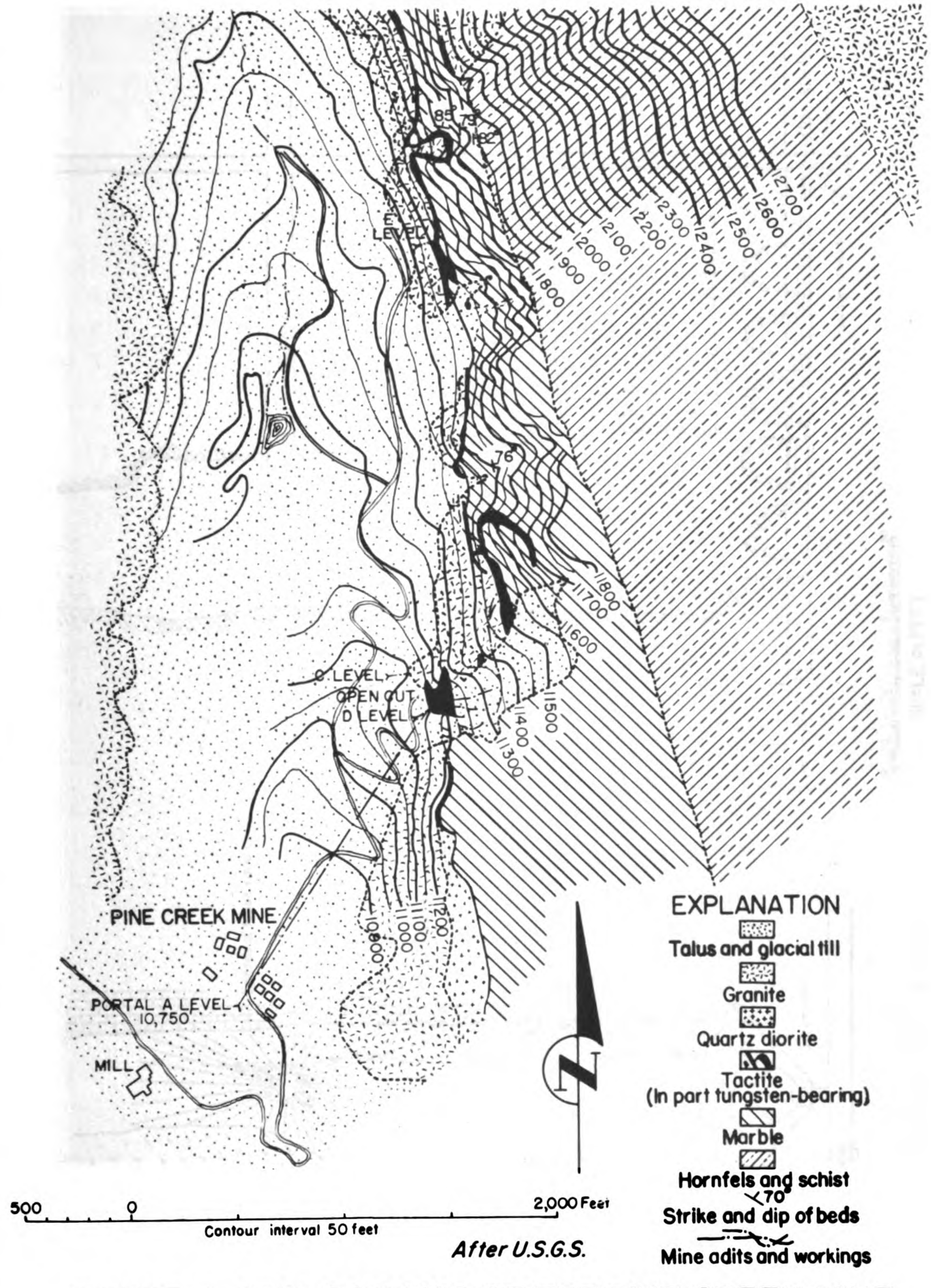

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FIGURE 3. GEOLOGIC MAP OF THE PINE CREEK MINE, INYO COUNTY, CALIFORNIA.

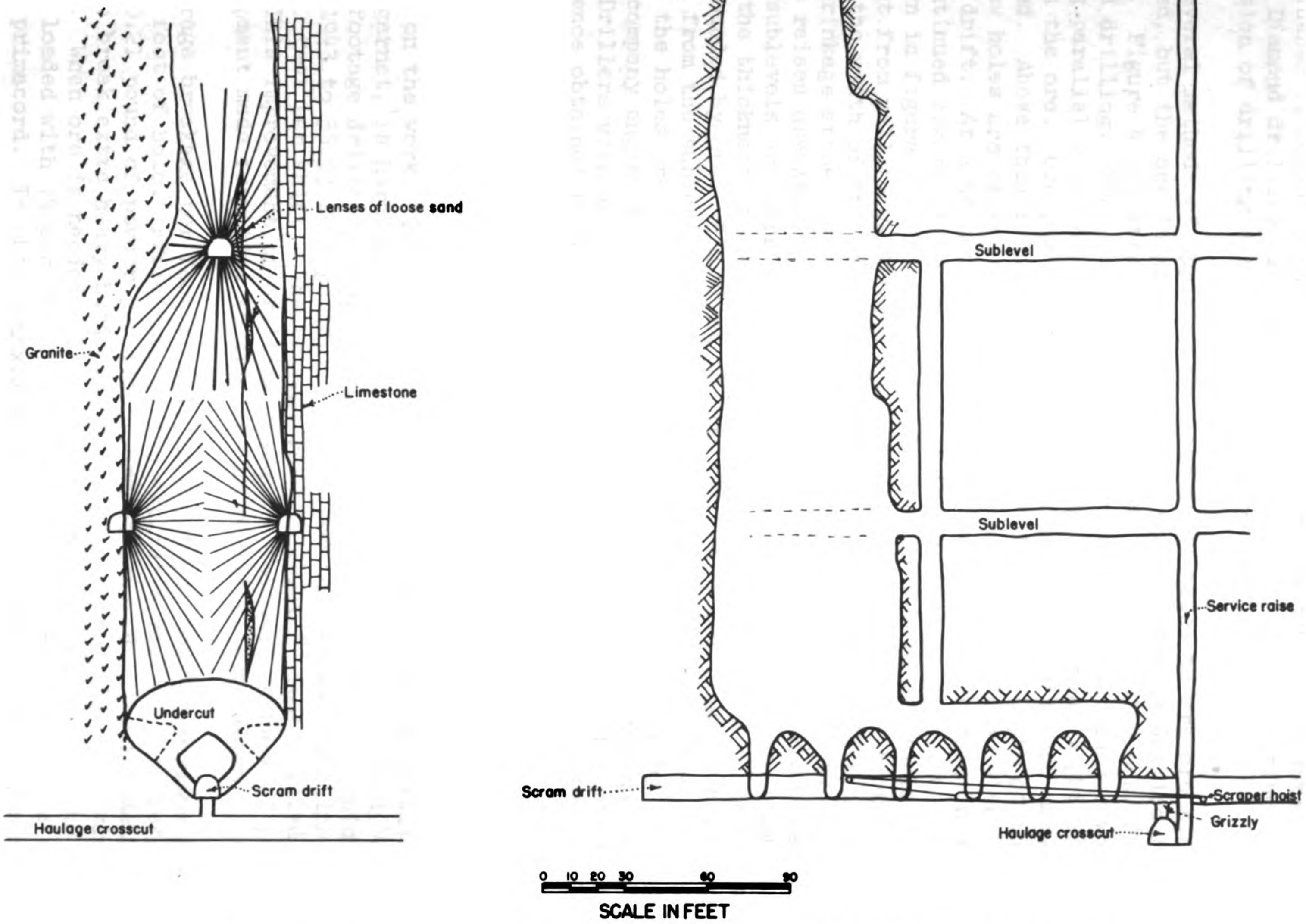

FIGURE 4. DIAMOND DRILLING IN PINE CREEK MINE, INYO COUNTY, CALIFORNIA.

spotted with a tugger hoist. Electric battery locomotives haul trains of the loaded cars outside to the crushing plant. The produce of the primary gyratory crusher is moved by aerial tramway 2.3 miles down the mountain to the mill. Diamond drilling is kept well in advance of stope blasting, so that suspension of drilling does not interrupt ore production.

Several methods of applying the long drill holes to ore breaking are employed, but the one in greatest use is the vertical ring drilled from sublevels. Figure 4 illustrates the development of a typical block of ore for diamond drilling. From the haulage level, usually in the granite wall and running parallel with the ore body, crosscuts are driven at right angles through the ore. Ore passes are raised from the crosscuts, and manways are provided. Above this raise a scram drift is driven the length of the block, and draw holes are broken upward at 45 degrees from points on alternate sides of the drift. At a height of 20 feet these raises are reversed in direction and continued upward at 45 degrees until the heading is over the scram drift, as shown in figure 4. From the tops of these draw-hole raises the block is undercut from wall to wall for its entire length. A slot is broken upward across the width of the block. This is done with hammer drills as an ordinary shrinkage stope and is carried to the full height of the block. Two service raises are driven to the next main level above, and from them 8- by 9-foot sublevels are carried along one or both walls of the ore body, depending on the thickness of the ore. Sublevels are occasionally placed so as to be surrounded by ore. Beginning at the slot, vertical rings of holes are drilled from the sublevels. Rings are given a burden of 6.5 feet, and the ends of the holes are 7 or 8 feet apart. A diagram of each ring is prepared by the company engineers showing the position, depth, and inclination of every hole. Drillers work according to these charts. Depth of holes may be altered on evidence obtained from an occasional cored hole. Uncored holes are bored with 1-7/16 inch concave bits on EX rods. The bits are manufactured by the contractor by a process of powder metallurgy.

Several types of drills have been used, including Boyles, Longyear, Sullivan, Longtin, and Chicago Pneumatic. At present there are six CP-5 machines on the work. The tactite ore, composed of metamorphic silicates, chiefly garnet, is hard and tough, making for slow drilling. In 1942, the average footage drilled per drill shift was 30.81. Improved technique raised this in 1943 to 35.53 feet per drill shift, and in 1944 each machine averaged around 50 feet per shift. The present rate is about 55 feet drilled per shift. This improvement of drilling speed has followed changes of proceedure and equipment made from time to time as the result of experience.

Average breakage per foot of hole is 2.5 tons, and the maximum is 4.8 tons per foot of hole. Efficiency of the explosive varies, with results of 0.15 to 0.21 pound of powder per ton of ore broken. Holes are sometimes sprung to break extra heavy burden. Drilling is carried far in advance of blasting. When ore is needed, all the holes in the ring next to the stope face are loaded with 75 percent dynamite and fired simultaneously with reinforced primacord. To obtain maximum breakage by fall, the stopes are kept nearly empty. Tests were made of 85 percent explosive, but the improvement in shattering effect was not enough to warrant the increased cost of the more powerful dynamite. Secondary blasting of the large blocks of broken ore is accomplished in the draw holes and at the grizzlies in the scram drifts.

All diamond drilling is done on contract by the Daniel Longtin Co. A price per foot drilled is paid when the drilling is done, and the final settlement, made after the holes are blasted, is on a basis of 50 cents per ton of 10 cubic feet, place measure. The footage payment is deducted from the final amount due for the tonnage broken. Originally the price paid per foot was $1.50. As performance improved, this payment was reduced successively to $1.35, $1.25, and $1.10. This year the company will pay $1 per foot for the "when drilled" price. Final payment at the rate of 50 cents per ton has remained the fundamental cost of drilling, loading, and firing the holes. Comparative costs of breaking ore by hammer-drill holes and by diamond-drill holes are so nearly the same that there is little choice between them on that score. Accounting showed the following average figures while both methods were being used on separate blocks of ore:

	Cost per ton of broken ores	
	By hammer drill	By diamond-drill
Contract price	$0.25	$0.50
Preparatory development...	.22	.08
Explosives	Incl. in contract	.043
Supervision and service...	.16	.01
Secondary blasting	.11	.11
	0.74	0.743

Under a contract for conventional rock drill stoping, the contractors purchase explosives from the company, whereas explosives are supplied by the company to the diamond drill contractors.

Diamond drills are being used on the surface this year at the Vanadium Co.'s mine. Long parallel holes will be put down in granite to break an opening 40 feet wide to the tactite outcrop at an elevation of 11,700 feet. The ore above this level will be diamond-drilled and blasted and then loaded by shovel on trucks for haulage to the crusher. This will be the second open cut in the outcrop, and a third will be prepared in the same manner during the season. Holes in the waste granite have a burden of 8 feet, which may be increased, because fragmentation is a secondary consideration. Bulldozers push the broken rock over the dump and seldom require secondary blasting. For contract payment purposes, granite is assumed to have a volume of 12 cubic feet per ton.

Another use of diamond-drill holes was for breaking a raise on a churn-drill hole. This work demands careful drilling, as the holes are blasted as in a burnt round, using the churn drill bore as the free face to which the holes break. The raise was later enlarged to a stope by further blasting of diamond-drill holes.

Development of a new block of ore is in progress between A level and C level. Stoping of this block will be done by diamond drilling horizontal holes from the two ends. The ends of the holes will overlap some 10 feet at

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the middle of the block. Corresponding rings drilled from each end will be blasted simultaneously.

Besides the regular stoping operations, diamond drills are used in mining pillars and reclaiming ore left between blocks.

At the Pine Creek mine, the advantage of using the diamond drills lies mainly in three points:

1. Safety. The drillers work in safe places, and the accident rate is lowered.

2. Reserve drilling. Rings of holes can be drilled far ahead of blasting, insuring steady mine production.

3. Manpower economy. Fewer men are required to drill a developed block of ore. This is an important item at Pine Creek, and was a vital consideration during the war.